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Sensitivity analyses of the 2025 chub mackerel stock assessment in the Northwest Pacific Ocean

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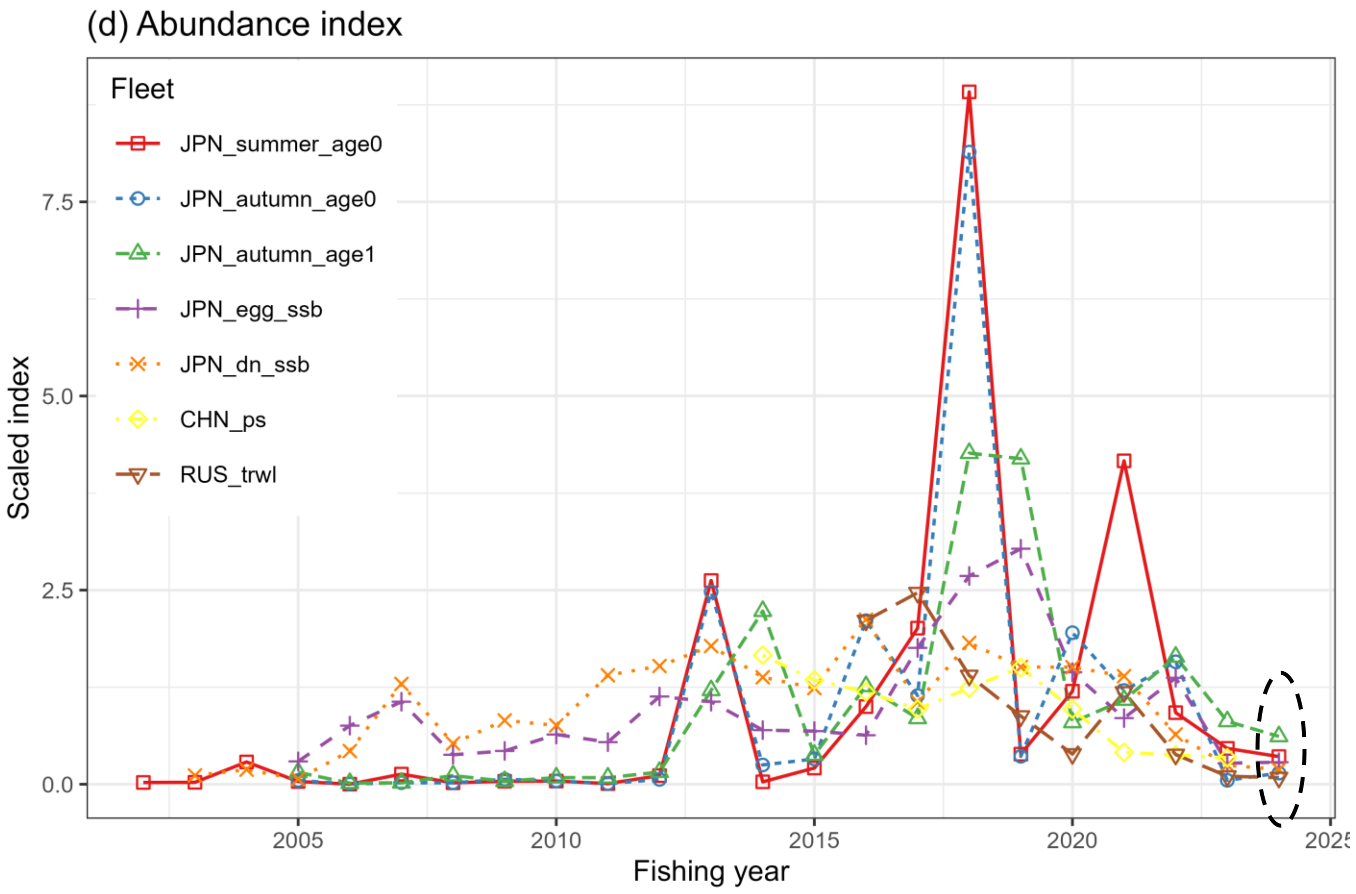
Summary

- We conducted sensitivity analyses to examine the impacts of observation uncertainty and model uncertainty in the 2025 stock assessment of chub mackerel in the Northwest Pacific.
- The analysis showed that the necessary assumptions of biological parameters to use 2024 fishing year abundance indices do not greatly affect stock abundance estimates.
- The analyses also show that models with the 2024 indices had higher prediction skill than models without the 2024 indices.
- We suggest using the most recent abundance indices in the stock assessment considering the robustness and predictability.
- Our results also suggest that process errors for age-1 and older fish and nonlinearity for age-0 and age-1 indices substantially change stock dynamics such as the strength of the 2013-year class, but these models exhibited bad model performance with respect to fit, prediction skill, and robustness.
- MSY-reference points were highly sensitive to the choices of data, biological parameters, and stock-recruitment relationship.
- This highlights the difficulty of using the MSY-reference points, and it may be appropriate to use more robust quantities based on historical SSB estimates as interim and empirical reference points, such as median or quartiles.

Introduction

- The candidate base cases were analyzed using the input data that the TWG CMSA has agreed on (NPFC-2025-TWG CMSA11-WP03)
- The model settings for the base case generally follows the last year's stock assessment despite minor revisions (NPFC-2025-TWG CMSA11-WP06)
- In this working paper, we conducted sensitivity analyses to evaluate further uncertainty that was not covered in the candidate base case document: uncertainty in input data (observation uncertainty) and model settings (model uncertainty).
- We focus on the effect of different biological parameters of the 2024 fishing year (FY2024), because last year's base case did not include the most recent abundance indices due to uncertainty of the biological parameters
- These sensitivity scenarios were compared by using performance measures (PMs) employed during the operating model development with some revision
- We also conducted hindcast cross validation in order to compare prediction skill among the models with different data sets in addition to a series of model diagnostics such as residual plots and retrospective analysis.

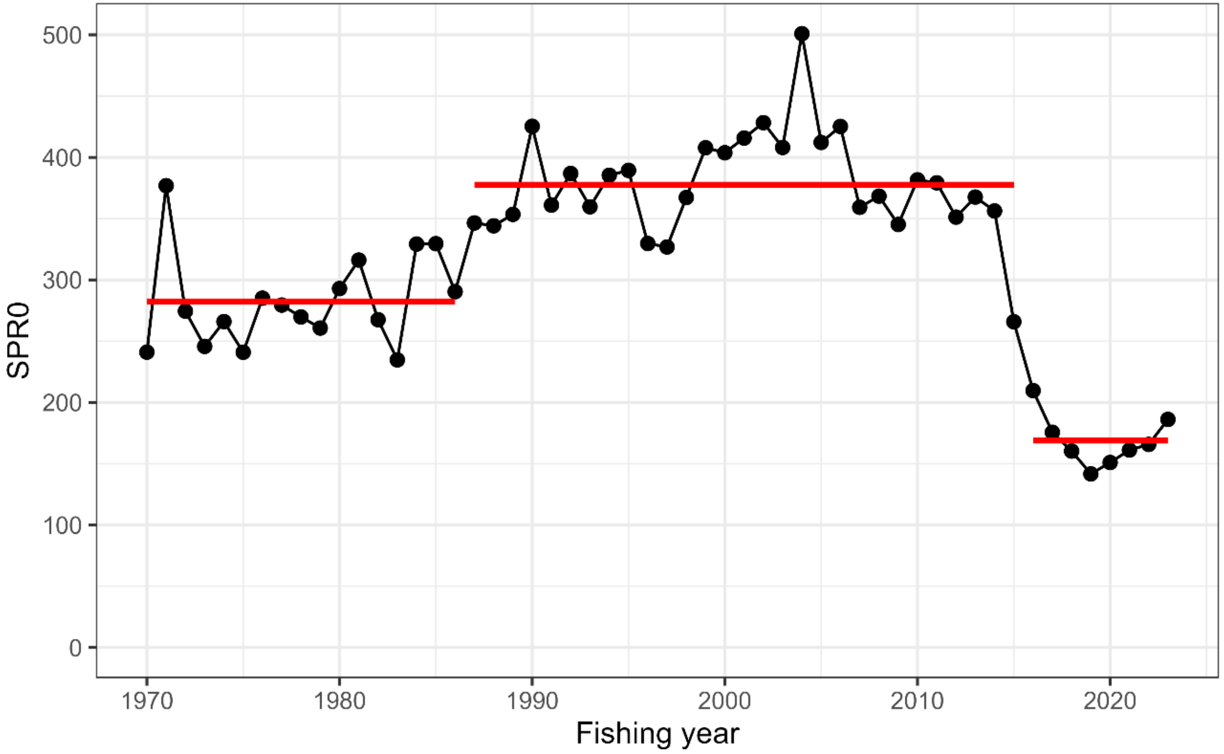
Abundance indices



- Abundance index values for FY2024 are available for six indices except Chinese CPUE
- Some of these indices are fitted to vulnerable stock biomass or SSB, and thus, weight-at-age and maturity-at-age data for FY2024 are required
- The proportion of catch number at age for Russian fishery in FY2024 is also required to use the Russian index in FY2024
- The SAM analysis using FY2024 can be conducted by projecting population dynamics one year ahead and treating FY2024 catch-at-age data as missing

Chage-point analysis to historical SPR0

Fig. 1



- Used the R package “changepoint”
- The result detected three different regimes of SPR0
- The last regime began in FY2016 (Fig. 1).
- Future projections last year were conducted using the average of weight-at-age and maturity-at-age from FY2016 to FY2022, which matches the results of change point analysis (maturity-at-age is constant since FY2016)
- Considering the continuity from last year and the result of change point analysis, we proposed using the FY2016-2023 average of weight- and maturity-at-age as those for FY2024 as a candidate base-case scenario (S02-Index24_1).
- We then considered three sensitivity scenarios in which the averaging period was revised to the most recent five years (FY2019-2023), three years (FY2021-2023), and one year (FY2023).

Scenario list 1

Table 1

Scenarios S02-09 have different assumptions on FY2024
- 4 cases on biological parameters in FY2024
- 2 cases on Russian catch proportions in FY2024

Scenario	Description	Index duration	Biological parameters in 2024	Russian catch proportion in 2024	Nonlinearity for abundance indices	Stock-recruit	Maturity	Process error for or age 1+
S01-InitBase	Initial base-case candidate	Through 2023	-	-	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Estimated
S02-Index24_1	Another candidate base case with indices of FY2024 (see right for details)	Through 2024	8 years ave (2016-2023)	3 years ave (2021-2023)	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Estimated
S03-Index24_2	Use indices of FY2024 with a different assumption from S02 (see right for details)	Through 2024	5 years ave (2019-2023)	3 years ave (2021-2023)	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Estimated
S04-Index24_3	Use indices of FY2024 with a different assumption from S02 (see right for details)	Through 2024	3 years ave (2021-2023)	3 years ave (2021-2023)	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Estimated
S05-Index24_4	Use indices of FY2024 with a different assumption from S02 (see right for details)	Through 2024	Latest year (2023)	3 years ave (2021-2023)	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Estimated
S06-Index24_5	Use indices of FY2024 with a different assumption from S02 (see right for details)	Through 2024	8 years ave (2016-2023)	5 years ave (2019-2023)	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Estimated
S07-Index24_6	Use indices of FY2024 with a different assumption from S02 (see right for details)	Through 2024	5 years ave (2019-2023)	5 years ave (2019-2023)	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Estimated
S08-Index24_7	Use indices of FY2024 with a different assumption from S02 (see right for details)	Through 2024	3 years ave (2021-2023)	5 years ave (2019-2023)	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Estimated
S09-Index24_8	Use indices of FY2024 with a different assumption from S02 (see right for details)	Through 2024	Latest year (2023)	5 years ave (2019-2023)	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Estimated

Scenario list 2

Table 1

Scenario	Description	Index duration	Biological parameters in 2024	Russian catch proportion in 2024	Nonlinearity for abundance indices	Stock-recruit	Maturity	Process error for or age 1+
S10-MAA_ChnJpn	Use average age of maturity between China and Japan	Through 2023	-	-	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Average of China and Japan	Estimated
S11-MAA_ChnJpn_idx24	Use average age of maturity between China and Japan and indices of FY2024	Through 2024	8 years ave (2016-2023)	3 years ave (2021-2023)	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Average of China and Japan	Estimated
S12-Mcom	Use age-common natural mortality (M=0.5)	Through 2025	-	-	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Estimated
S13-Mcom_idx24	Use age-common natural mortality (M=0.5) and indices of FY2024	Through 2026	8 years ave (2016-2023)	3 years ave (2021-2023)	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Estimated
S14-SHS	Use smooth hockey stick (SHS)	Through 2023	-	-	Estimate nonlinearity for ages 0 and 1 indices	Smooth HS	Japan	Estimated
S15-SHS_idx24	Use smooth hockey stick (SHS) and indices of FY2024	Through 2024	8 years ave (2016-2023)	3 years ave (2021-2023)	Estimate nonlinearity for ages 0 and 1 indices	Smooth HS	Japan	Estimated
S16-NoProcErr	Assume a very small process errors for numbers older than age 0	Through 2023	-	-	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Fixed at SD=0.01
S17-NoProcErr_idx24	Assume a very small process errors for numbers older than age 0 and use indices of FY2024	Through 2024	8 years ave (2016-2023)	3 years ave (2021-2023)	Estimate nonlinearity for ages 0 and 1 indices	Beverton-Holt	Japan	Fixed at SD=0.01
S18-Fix_b1	Fix nonlinear coefficients at b=1 for all indices	Through 2023	-	-	Assume linearity for all indices	Beverton-Holt	Japan	Estimated
S19-Fix_b1_idx24	Fix nonlinear coefficients at b=1 for all indices and use indices of FY2024	Through 2024	8 years ave (2016-2023)	3 years ave (2021-2023)	Assume linearity for all indices	Beverton-Holt	Japan	Estimated

Sensitivity analyses were conducted regarding maturity at age, natural mortality, stock-recruitment relationship, process errors for older than age 0, and nonlinearity of abundance indices

Performance measures

Newly added the historical median and the first and third quartiles of SSB during FY1970-2023 and the most recent three-year average of SSB to these historical quantities

PM	Description
TBy2023	Total stock biomass in FY2023 (1,000 MT)
SSBy2023	Spawning stock biomass in FY2023 (1,000 MT)
Ry2019	The number of recruits in FY2019 (million)
Ry2020	The number of recruits in FY2020 (million)
Ry2021	The number of recruits in FY2021 (million)
Ry2022	The number of recruits in FY2022 (million)
Ry2023	The number of recruits in FY2023 (million)
AFy2019	Weighted average of F-at-age by estimated catch-at-age in FY2019
AFy2020	Weighted average of F-at-age by estimated catch-at-age in FY2020
AFy2021	Weighted average of F-at-age by estimated catch-at-age in FY2021
AFy2022	Weighted average of F-at-age by estimated catch-at-age in FY2022
AFy2023	Weighted average of F-at-age by estimated catch-at-age in FY2023
Ey2019	Exploitation rate (estimated catch divided by stock biomass) in FY2019
Ey2020	Exploitation rate in FY2020
Ey2021	Exploitation rate in FY2021
Ey2022	Exploitation rate in FY2022
Ey2023	Exploitation rate in FY2023
B/Bmsy	Ratio of total biomass in FY2022 to B_{MSY}
SSB/SSBmsy	Ratio of spawning biomass in FY2022 to SSB_{MSY}
SSBmsy/SSBmax	Ratio of SSB_{MSY} to the historical maximum of spawning biomass

Calculate biological REFs using the recent 8-year (FY2016-2023) average (default) the all-year average of biological parameters

PM	Description
currentSPR/SPR0	Ratio of spawners per recruit (SPR) in the average of FY2021-2023 to that without fishing
SSBmedian	Median spawning biomass from FY1970 to 2023
deple_median_last3	Ratio of the average of spawning biomass in FY2020-2022 to its historical median
SSB_Q1	The first quartile (25th percentile) of spawning biomass from FY1970 to 2023
Deple_Q1_last3	Ratio of the average of spawning biomass in FY2020-2022 to its first quartile
SSB_Q3	The third quartile (75th percentile) of spawning biomass from FY1970 to 2023
Deple_Q3_last3	Ratio of the average of spawning biomass in FY2020-2022 to its third quartile
F_{MED}/Fcur	Ratio of F median to current F (average F in FY2020-2022)
F0.1/Fcur	Ratio of F0.1 to current F (average F in FY2020-2022)
FpSPR.30.SPR/Fcur	Ratio of F30%SPR to current F (average F in FY2020-2022)
FpSPR.40.SPR/Fcur	Ratio of F40%SPR to current F (average F in FY2020-2022)
FpSPR.50.SPR/Fcur	Ratio of F50%SPR to current F (average F in FY2020-2022)
FpSPR.60.SPR/Fcur	Ratio of F60%SPR to current F (average F in FY2020-2022)
FpSPR.70.SPR/Fcur	Ratio of F70%SPR to current F (average F in FY2020-2022)
Fmsy/Fcur	Ratio of F_{MSY} to current F (average F in FY2020-2022)
Bmsy	Deterministic MSY reference point for total biomass (1,000 MT)
SSBmsy	Deterministic MSY reference point for spawning stock biomass (1,000 MT)
H	Steepness
SSB0	Virgin spawning stock biomass (1,000 MT)
SSBmsy/SB0	Ratio of SB_{MSY} to SB0
FmsySPR	%SPR for F_{MSY}
B/Bmsy	Ratio of total biomass in FY2022 to B_{MSY}
SSB/SSBmsy	Ratio of spawning biomass in FY2022 to SSB_{MSY}
SSBmsy/SSBmax	Ratio of SSB_{MSY} to the historical maximum of spawning biomass

Hindcast cross validation

- AIC and retrospective analysis cannot be compared for models with different datasets about availability of abundance indices (with or without FY2024)
- For comparing predictive skill when using different data and model structures, hindcast cross-validation (CV) is sometimes utilized (Kell et al. 2016; Carvalho et al. 2021)
- The hindcast CV evaluates predictive power based on observed values rather than unobserved, estimated values
- The spawning egg abundance index is used for evaluating predictive performance because it correlates well with SSB and is a crucial indicator of population reproductive potential

- Conducted a retrospective analysis and predicted future index values from predicted SSB and estimated proportionality constant
- While the time lag for catch at age is same for both scenarios, the time lag is two years for the base case but one year for the sensitivity scenario

Index year for prediction	Scenarios without FY2024 indices	Scenairos with FY2024 indices
2024	CAA: up to 2022 Indices: up to 2022	CAA: up to 2022 Indices: up to 2023
2023	CAA: up to 2021 Indices: up to 2021	CAA: up to 2021 Indices: up to 2022
…		
2018	CAA: up to 2016 Indices: up to 2016	CAA: up to 2016 Indices: up to 2017

- The mean absolute scaled error (MASE) is often used as a robust statistic for the hindcast CV (Hyndman and Koehler 2006; Carvalho et al. 2021):

$$MASE = \frac{\frac{1}{n}\sum_{y=2024-n+1}^{2024}\left|I_y - \hat{I}_{y|y-h}\right|}{\frac{1}{n}\sum_{y=2024-n+1}^{2024}\left|I_y - I_{y-h}\right|}$$

Results

Overview of model diagnostics for convergence

In all 19 scenarios, the parameter estimation successfully converged, and the positive definite values of the Hessian matrix required to calculate the estimation error were obtained (see Table 3).

The final gradient values were also close to zero for all scenarios.

Performance measures (PMs) under the candidate base-case scenarios

- The current SSB (~~1.32–1.41 million~~ 132-141 thousand tons in FY2023) was below the median of historical SSB (~~2.89 million~~ 289 thousand tons) but remained above the first quartile (~~1.07 million~~ 107 thousand tons) (Table 4).
- When biological parameters averaged over FY2016–2023 were used, the percent SPR under current fishing mortality (F) was estimated at approximately 16–17%, while %SPR at F_{MSY} was estimated at 67–68%.
- The current fishing pressure exceeded all calculated F reference points.
- The estimated steepness was 0.35–0.36, and SSB_{MSY} was higher than the historical maximum SSB.

PM	S01-InitBase	S02-Index24_1
TBy2023	1,433	1,375
SSBy2023	141	132
Ry2019	5,158	5,079
Ry2020	8,038	7,877
Ry2021	8,722	8,680
Ry2022	7,259	7,008
Ry2023	3,139	3,400
AFy2019	0.359	0.361
AFy2020	0.488	0.495
AFy2021	0.570	0.584
AFy2022	0.483	0.513
AFy2023	0.325	0.355
Ey2019	0.144	0.145
Ey2020	0.195	0.198
Ey2021	0.199	0.202
Ey2022	0.152	0.160
Ey2023	0.122	0.129
currentSPR/SPR0	0.174	0.162
SSBmedian	289	289
deple_median_last3	0.912	0.892
SSB_Q1	107	107
deple_Q1_last3	2.463	2.404
SSB_Q3	721	724
deple_Q3_last3	0.365	0.356
Fmed/Fcur	0.312	0.310
F0.1/Fcur	0.902	0.838
FpSPR.30.SPR/Fcur	0.613	0.580
FpSPR.40.SPR/Fcur	0.435	0.412
FpSPR.50.SPR/Fcur	0.311	0.295
FpSPR.60.SPR/Fcur	0.219	0.207
FpSPR.70.SPR/Fcur	0.147	0.139
Fmsy/Fcur	0.160	0.161
Bmsy	6,551	5,417
SSBmsy	1,915	1,561
h	0.354	0.364
SSB0	4,680	3,863
SSBmsy/SSB0	0.409	0.404
FmsySPR	0.679	0.665
B/Bmsy	0.219	0.254
SSB/SSBmsy	0.074	0.084
SSBmsy/SSBmax	1.373	1.116

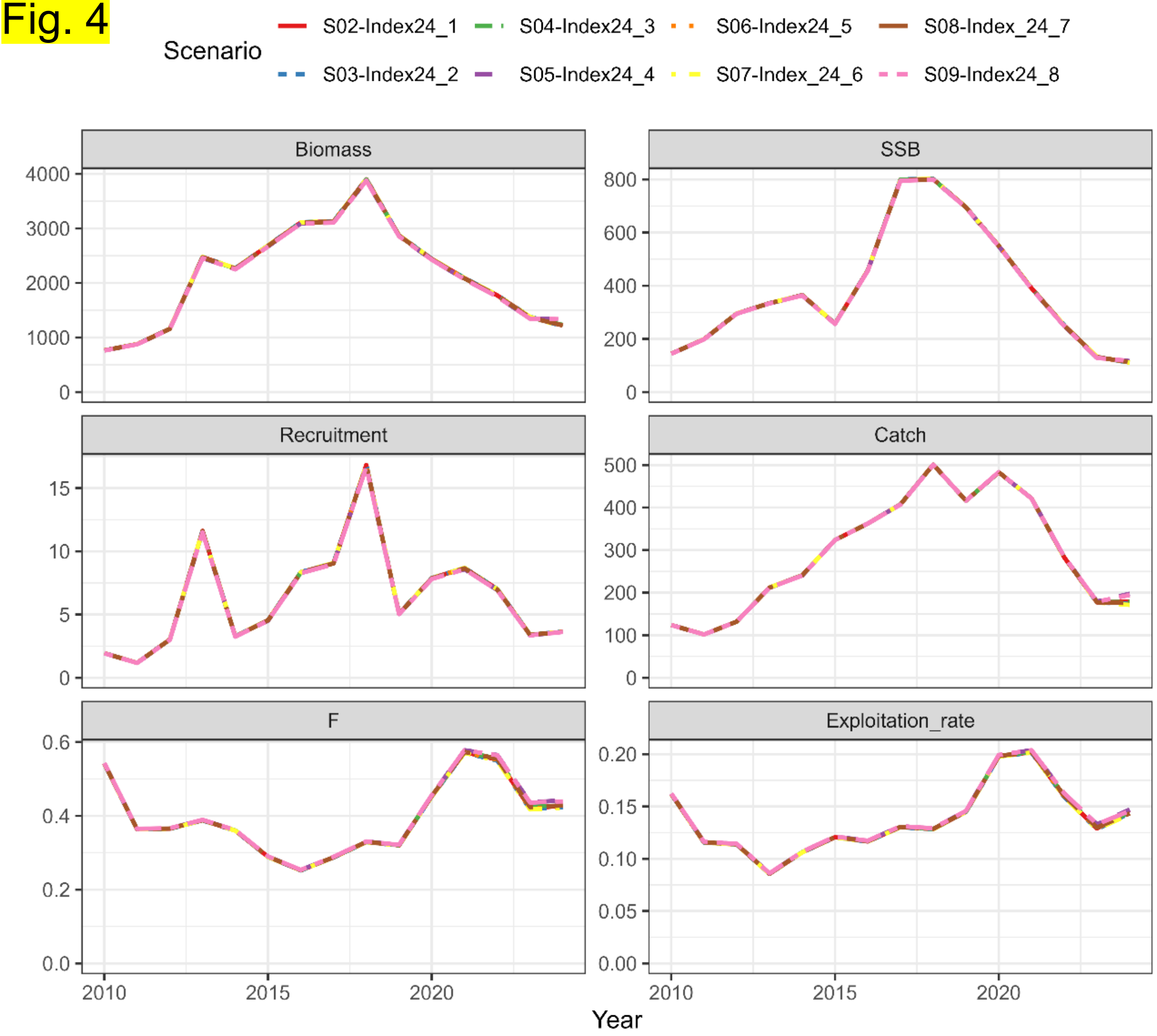
PMs under the candidate base-case scenarios when the biological parameters were averaged over all years

- When the biological parameters were averaged over all years (FY1970-2023), all F reference points except F0.1 increased (Table 5).
- However, the current F still exceeded all F reference points except F_{MED}.
- Under this assumption, steepness increased to 0.50–0.51, and SSB_{MSY} more than doubled, compared to the cases taking FY2016-2023 average.

PM	S01-InitBase	S02-Index24_1
currentSPR/SPR0	0.291	0.278
Fmed/Fcur	1.091	1.067
F0.1/Fcur	0.902	0.838
FpSPR.30.SPR/Fcur	0.964	0.911
FpSPR.40.SPR/Fcur	0.644	0.609
FpSPR.50.SPR/Fcur	0.440	0.416
FpSPR.60.SPR/Fcur	0.299	0.282
FpSPR.70.SPR/Fcur	0.194	0.184
Fmsy/Fcur	0.422	0.415
Bmsy	11,882	9,597
SSBmsy	4,158	3,317
h	0.501	0.512
SSB0	11,892	9,613
SSBmsy/SSB0	0.350	0.345
FmsySPR	0.511	0.501
B/Bmsy	0.121	0.143
SSB/SSBmsy	0.034	0.040
SSBmsy/SSBmax	2.982	2.371

Effects of FY2024 indices on abundance estimates

Fig. 4



- Changes in the FY2024 weight-at-age and the proportion of Russian catch had little effect on the estimated stock biomass and the suite of PMs (Fig. 4, Table 4).
- The differences in AIC values were also small (less than 1) (Table 3).

Effects of FY2024 indices on biomass-based reference points

PM	S01-InitBase	S02-Index24_1
TBy2023	1,433	1,375
SSBy2023	141	132
currentSPR/SPR0	0.174	0.162
SSBmedian	289	289
deple_median_last3	0.912	0.892
SSB_Q1	107	107
deple_Q1_last3	2.463	2.404
SSB_Q3	721	724
deple_Q3_last3	0.365	0.356
Bmsy	6,551	5,417
SSBmsy	1,915	1,561
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SSB0	4,680	3,863
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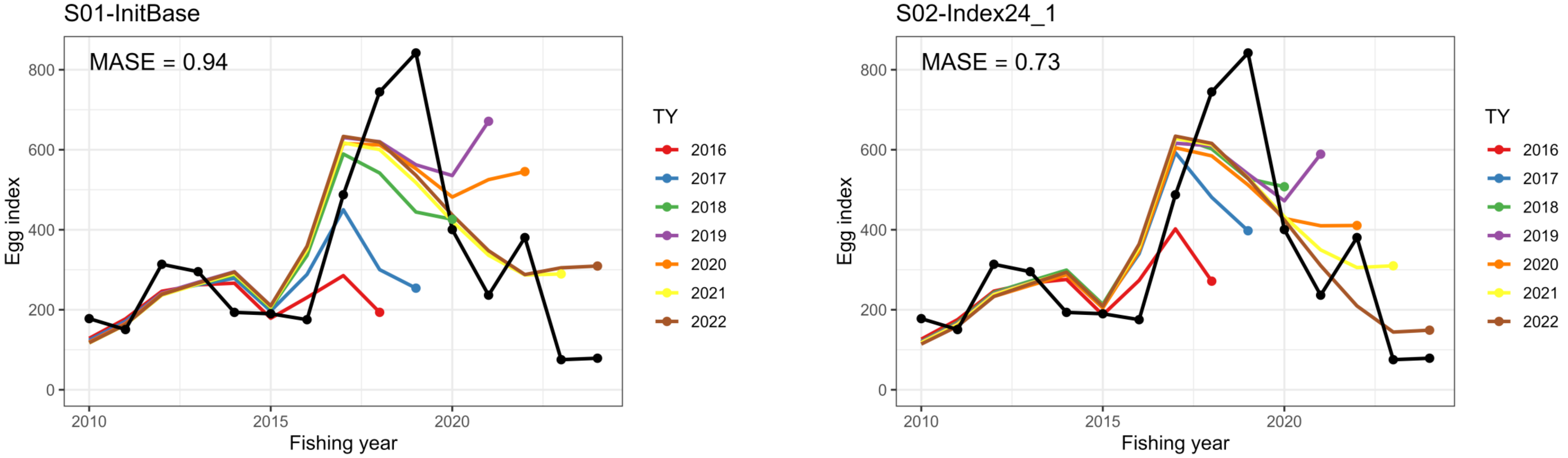
B/Bmsy	0.219	0.254
SSB/SSBmsy	0.074	0.084
SSBmsy/SSBmax	1.373	1.116

- The inclusion or exclusion of FY2024 abundance indices had little effect on the state variables, but it did influence the shape of the stock-recruitment relationship, resulting in changes to SSB0 and SSB_{MSY} estimates (Table 4).
- Under the S01-InitBase scenario, where biological parameters averaged over FY2016–2023 were used, SSB_{MSY} was estimated at 1.915 million tons.
- In contrast, under the S02-Index24_1 scenario, it was estimated at 1.561 million tons.
- In addition, under last year's base-case scenario (S28-ProcEst), SSB_{MSY} was estimated at 2.905 million tons, indicating a decrease in SSB_{MSY} due to the incorporation of the most recent data.
- This suggests that SSB_{MSY} is sensitive to data revisions and updates.
- Furthermore, in the current stock assessment, SSB_{MSY} estimates in most scenarios (except for a few) still exceeded historical maximum SSB (Table 4).
- Historical quartiles of SSB were more robust against the inclusion or exclusion of FY2024 indices

Effects of FY2024 indices on prediction skill

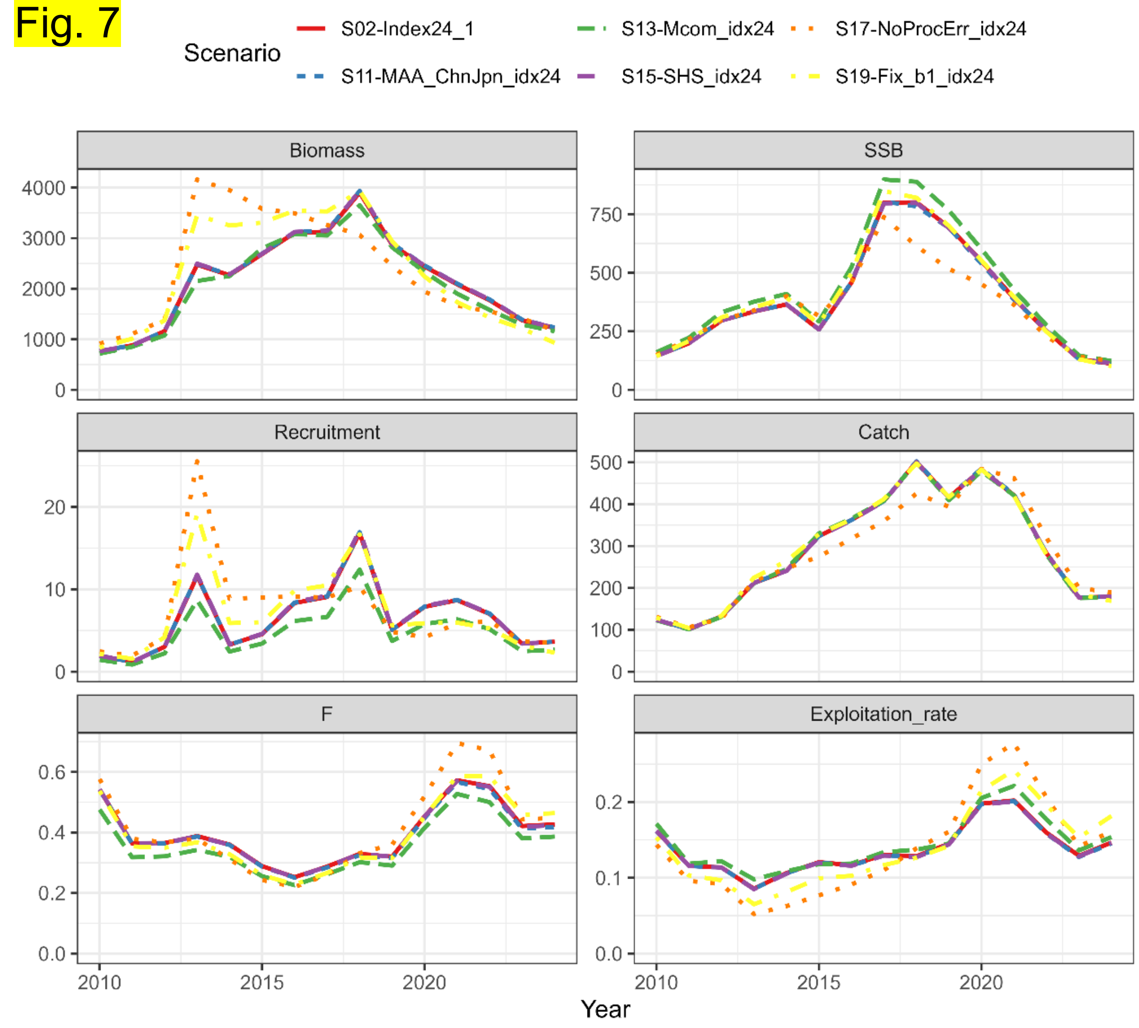
Fig. 5 (top two panels)



- The scenarios with the latest abundance indices showed lower MASE values in the hindcast cross validation than the corresponding scenarios without the latest indices (Table 3).
- The MASE decreased from 0.94 for S01-InitBase to 0.73 for S02-Index24_1 by including FY2024 indices (Fig. 5).
- This suggests that using the newest information of abundance indices helps improve the prediction skill against the data of spawning egg abundance.

State variable estimates under other scenarios

Fig. 7



This figure shows the results when FY2024 indices are included, but the results when it is not included are similar (see Fig. 6)

- The latest SSB estimates are quite robust.
- The impacts of maturity at age and SR relationship are lowest
- The change in natural mortality affects the scale of recruitment
- The changes in the assumptions on process errors and nonlinearity of abundance indices have highest impacts especially for recruitment and biomass trends
- I will pick up the model performance of these scenarios later

Smooth hockey-stick model

Fig. 8

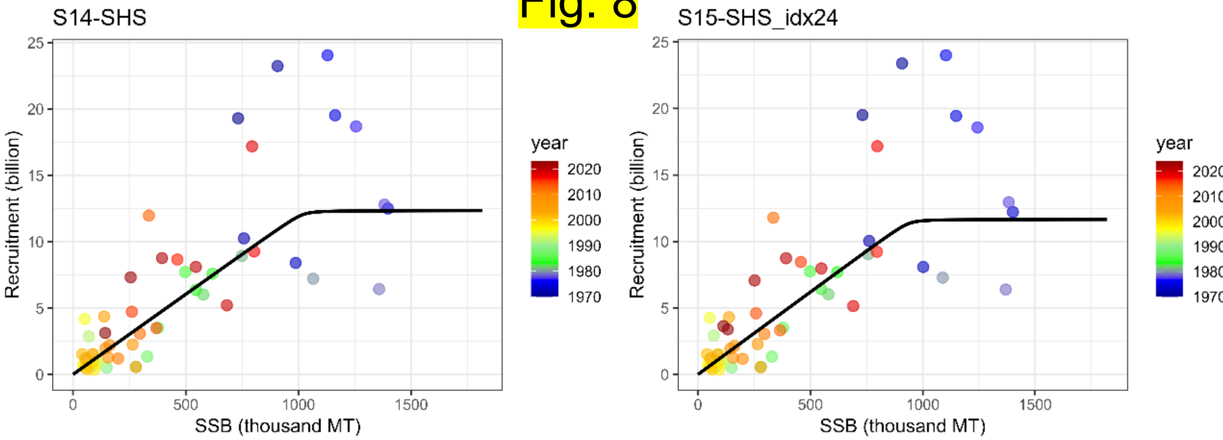
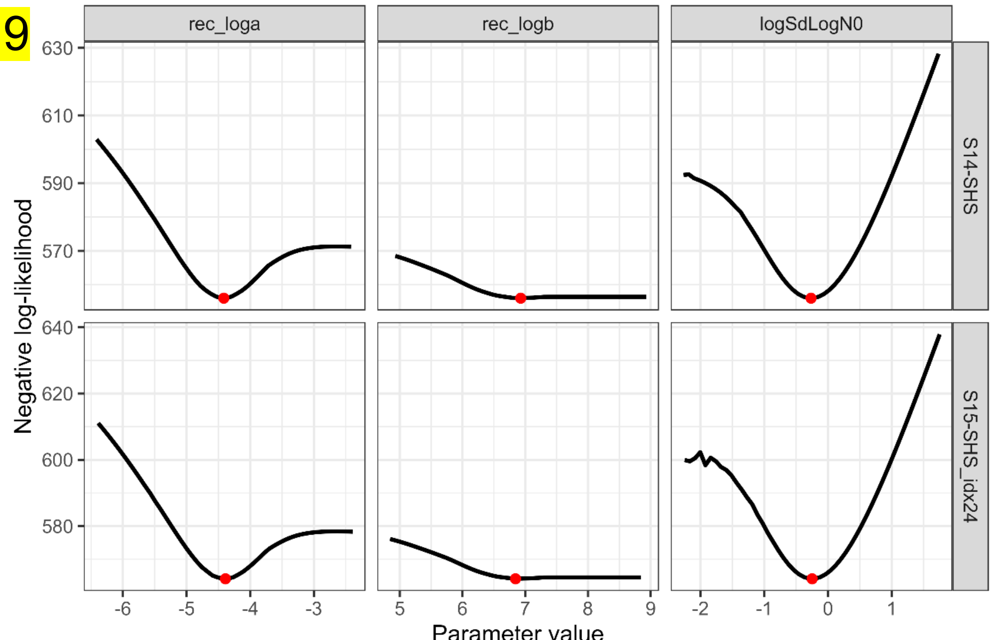


Fig. 9

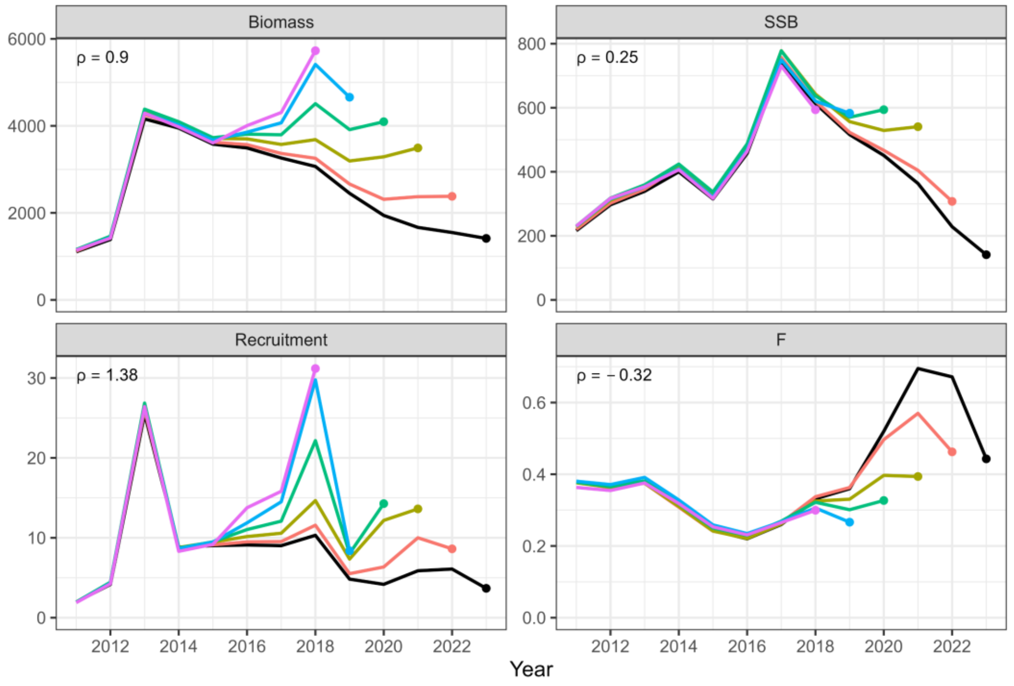


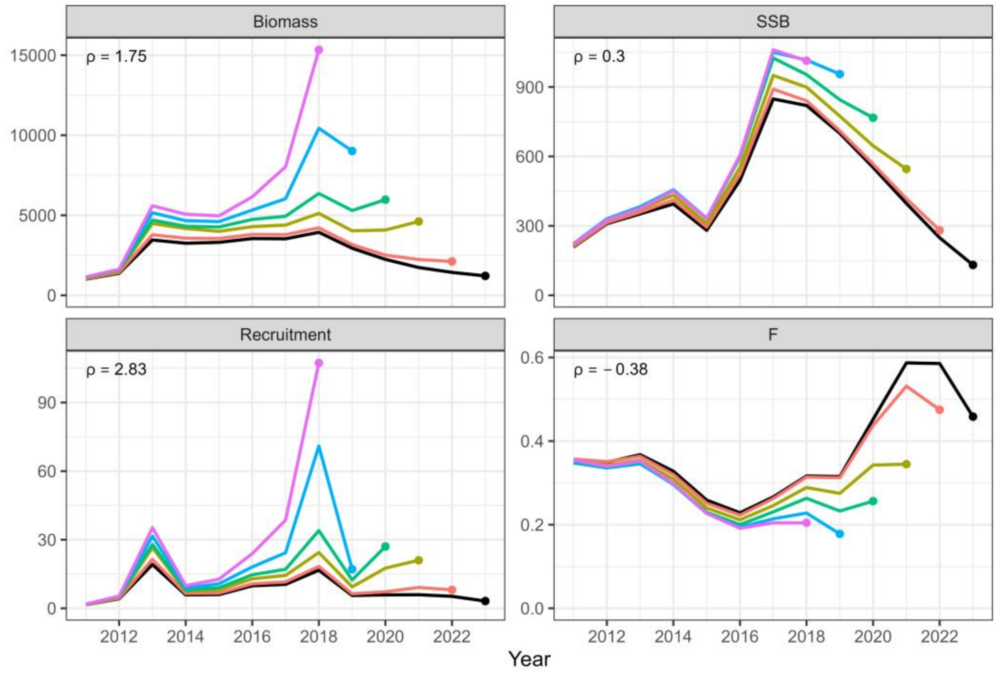
PM	S01-InitBase	S02-Index24_1	S14-SHS	S15-SHS_idx24
TBy2023	1,433	1,375	1,443	1,384
SSBy2023	141	132	143	133
Fmsy/Fcur	0.160	0.161	0.325[1]	0.320[1]
Bmsy	6,551	5,417	4,379[1]	4,105[1]
SSBmsy	1,915	1,561	1,021[1]	940[1]
h	0.354	0.364	0.510	0.523[2]
SSB0	4,680	3,863	2,086	1,969[1]
SSBmsy/ SSB0	0.409	0.404	0.490	0.477[1]
FmsySPR	0.679	0.665	0.490	0.477[1]
B/Bmsy	0.219	0.254	0.329	0.337[1]
SSB/ SSBmsy	0.074	0.084	0.140	0.141[1]
SSBmsy/ SSBmax	1.373	1.116	0.731	0.671[1]

- The SHS stock-recruitment relationships were estimated with smooth breakpoints at SSB = 1.02 million ton for S14-SHS and SSB = 0.94 million ton for S15-SHS_idx24.
- The likelihood profiling showed successful optimization of the estimated parameters, despite being insensitive to changes in the breakpoint location
- When the SHS relationship was used, F_{MSY} was estimated to be higher and SSB_{MSY} to be lower compared to the estimates based on the BH relationship
- But the SSB exceeded SSB_{MSY} only before 1980, and has remained below SSB_{MSY} since then

Effects of process errors and nonlinearity of abundance indices on model performances (1)

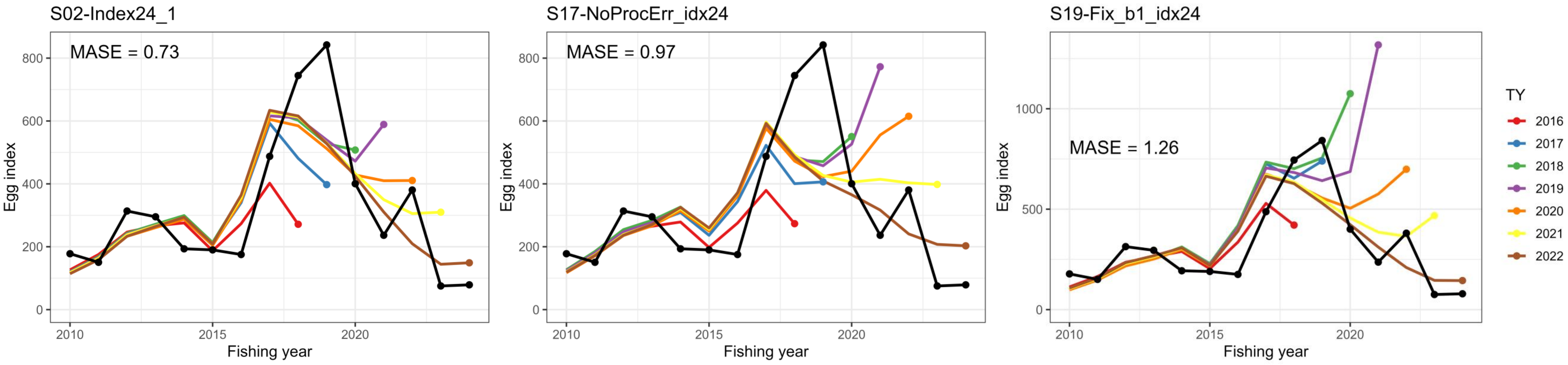
- The largest change in the stock biomass pattern occurred for the scenarios (S14-15) in which process errors for age-1 and older were turned off and the scenarios (S18-19) in which the indices for age-0 and age-1 follow a linear relationship
- These scenarios have higher AIC and retrospective patterns than the candidate base case scenarios





Effects of process errors and nonlinearity of abundance indices on model performances (2)

These scenarios exhibited much poorer predictive performance than the other scenarios, as MASE in the hindcast cross-validation



- From a statistical view, it is considered more appropriate to estimate process errors for age-1+ fish and to assume nonlinearity in the indices for age-0 and age-1 fish.
- These findings raise important biological questions: (1) What specific factors—such as mortality or migration—underlie the process errors for age-1+ fish? and (2) Why do the survey indices from trawl surveys targeting age-0 and age-1 fish show a tendency toward hyperdepletion?

Consideration about the inclusion of FY2024 indices

- The estimated stock biomass was highly robust to assumptions related to biological parameters when incorporating the most recent abundance indices.
- The sensitivity analysis suggests that the impact of the uncertainty on the estimation is minimal if these parameters fall within the recent range of values.
- Using the most recent abundance indices in last year’s assessment would have reduced the extent of the downward revision observed in this year’s assessment.
- Using the most recent abundance indices shows a higher prediction skill in hindcast cross validation
- The advantage of using the data up to the most recent year is effective for shortening time lag up to management implementation
- These findings suggest that incorporating recent abundance indices—along with using recent average values for biological parameters—can contribute to improving the stability and reliability of stock assessments while uncertainties regarding the assumptions about biological parameters are minimal

Consideration on biomass reference points

- MSY-based reference points are highly sensitive to model configurations and input data.
- For chub mackerel, which exhibit substantial variability in body weight and maturity-at-age, the SSB_{MSY} estimated under the BH stock–recruitment relationship can differ by more than a factor of two depending on whether recent biological parameters or long-term averages are used.
- SSB_{MSY} estimates also changed significantly depending on whether the most recent abundance indices were included.
- On the other hand, statistics of historical median or quantiles of SSB were robust across almost all scenarios S01-19.
- Given the high sensitivity of MSY reference points to input data and biological parameters, using the historical median or quartiles of SSB would serve as a realistic basis for empirical reference points.
- However, it should be noted that the quartiles are consistently lower than SSB_{MSY} and should be considered merely as *interim* reference points rather than *proxies* for MSY.
- Specifically, the first, second (median), third quartiles correspond to 3.7–11.4%, 11.5–30.7%, and 23.2–76.8% of SSB_{MSY}, respectively, across all scenarios.
- Interestingly, stock assessments since last year have shown that the inclusion of new data tends to slightly shift the shape of the stock–recruitment relationship and consistently leads to lower SSB_{MSY} estimates.
- Although SSB_{MSY} is currently estimated to be higher than the historical maximum with high uncertainty, it is possible that stronger density dependence will be detected in the future, resulting in SSB_{MSY} estimates that fall within historical ranges.